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Polaris: Mass and Multiplicity

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Abstract. Polaris, the nearest and brightest classical Cepheid, is a member of at least a triple system. It has a wide (18″) physical companion, the F-type dwarf Polaris B. Polaris itself is a single-lined spectroscopic binary with an orbital period of ∼30 years (Kamper 1996). By combining *Hipparcos* measurements of the instantaneous proper motion with long-term measurements and the Kamper radial-velocity orbit, Wielen *et al.* (2000) have predicted the astrometric orbit of the close companion. Using the *Hubble Space Telescope* and the Advanced Camera for Surveys' High-Resolution Channel with an ultraviolet (F220W) filter, we have now directly detected the close companion. Based on the Wielen *et al.* orbit, the *Hipparcos* parallax, and our measurement of the separation (0″.176 ± 0″.002), we find a preliminary mass of 5.0 ± 1.5 $M_\odot$ for the Cepheid and 1.38 ± 0.61 $M_\odot$ for the close companion. These values will be refined by additional *HST* observations scheduled for the next 3 years.

We have also obtained a *Chandra* ACIS-I image of the Polaris field. Two distant companions C and D are not X-rays sources and hence are not young enough to be physical companions of the Cepheid. There is one additional stellar X-ray source in the field, located 253″ from Polaris A, which is a possible companion. Further investigation of such a distant companion is valuable to confirm the full extent of the system.

Keywords. Cepheids, masses, multiplicity, *Chandra*, *HST*

1. Introduction

Polaris, like most massive stars, is a member of a multiple system. It is also a supergiant (F5 Ib) which is the nearest and brightest classical Cepheid. It is a low amplitude, somewhat quirky, Cepheid with a variable amplitude, which is pulsating in the first overtone mode, as shown by the *Hipparcos* parallax (Feast & Catchpole 1997)

The goals of this discussion are to present preliminary results on two topics. The first is a direct dynamical measurement of the mass, which is of particular interest because Polaris Aa is a Cepheid. The second is to explore how many physical companions belong to the system, which is of interest as the "footprints" of star formation.

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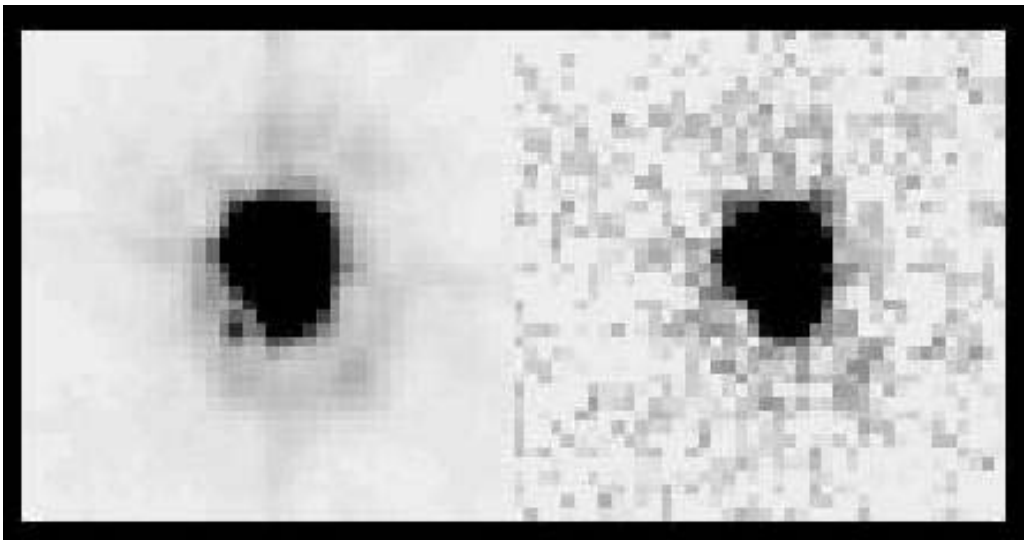

Figure 1. Left: Polaris Aa + Ab taken with the *HST* ACS HRC F220W filter (coadded images). The companion Ab can be seen at approximately 7 o'clock. The image is approximately 1″ on a side. Right: Polaris B from the same image shown to the same scale.

2. Mass

In order to determine the mass, an orbit must be derived. Polaris is a member of a ∼30-year spectroscopic system. We have used the orbit redetermined by Kamper (1996). He includes high-precision velocities, which is important since the orbital velocity amplitude is only 4 km sec^{-1}. Wielen *et al.* (2000) made an important breakthrough when they used *Hipparcos* proper motions to derive an inclination for the system.

However, no further information could be determined about the mass because the companion had never been detected, nor the separation measured. We have obtained a *Hubble Space Telescope* (*HST*) Advanced Camera for Surveys (ACS) High Resolution Channel (HRC) image on 2 August 2005 (Figure 1). The companion can be seen in Figure 1 (left) at about "7 o'clock".

Because the point-spread function (PSF) is not completely symmetric, and faint wings can be seen in Figure 1, we have performed several tests to confirm the companion detection. The companion Polaris B is also in the images, and is shown in Figure 1 (right). It is noisier than A since B is 6 mag fainter. However the PSF is very similar, and there is no artifact at the location of the companion of Polaris A = Polaris Ab. In addition, we have examined several images of single white dwarfs taken with the same instrumentation from the *HST* archive, and also find no indication of an artifact at the location of Ab. For a full discussion of the 2005 observation and a second image obtained in 2006, see Evans *et al.* (2007).

Combining the orbit with the separation measured from the *HST* images (0″.176 ± 0″.002), we find a mass of 5.0 ± 1.5 $M_\odot$ for the Cepheid and 1.38 ± 0.61 $M_\odot$ for the close companion. These values are preliminary and will be refined through successive *HST* observations.

3. Companions

The second aspect of this study is an investigation of the number of members of the system. While there are many ways to detect a binary companion in a system, it is much more difficult to be certain that the full list of members has been identified.

In the Polaris system, there are 2 highly probable companions, Ab, the member of the spectroscopic system, and Polaris B. Polaris B (19″ distant) is a probable physical companion on velocity grounds (Kamper 1996). Two fainter, more distant stars (C and D) might be companions and would be dK stars if they are at the distance of Polaris.

Does a system with three stars more massive than the sun have a number of low-mass companions as would be predicted by the initial mass function? In order to investigate this, we used the following approach. Any low-mass companions (mid-F spectral type and later) as young as the Cepheid would produce X-rays. See, for instance, the study of the α Per cluster (Randich *et al.* 1996).

We have obtained a 10 ksec *Chandra* image to look for low-mass companions. Stars C and D do not appear on the X-ray image, and hence are not young companions. Their motion has also been found (by BDM) to be incompatible with the Polaris system. We do find X-rays at the location of Aa + Ab and are working to determine whether they come from the Cepheid or the companion. B was not detected in X-rays, but that is not surprising for an early F star. In addition there are a number of background AGNs in the image. They can be distinguished from stars since they do not have optical counterparts on the 2MASS images, whereas stars at the distance of Polaris do have counterparts. However, there is one X-ray source that does have a 2MASS counterpart consistent with an early M star. This source "E" becomes the one candidate for a further member of the system in the $16' \times 16'$ *Chandra* ACIS-I field.

In summary, only a late dM star would have remained undetected on the *Chandra* image. This means we have searched for companions to approximately a mass ratio of 0.1. The full content of the system is made up of the Cepheid and two probable companions with one possible additional low-mass companion.

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